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Tensile Properties of Beef Semitendinosus Muscle as Affected by Heating Rate and End Point Temperature

Carolyn Lucille Barker

To the Graduate Council:

I am submitting herewith a thesis written by Carolyn Lucille Barker entitled "Tensile Properties of Beef Semitendinosus Muscle as Affected by Heating Rate and End Point Temperature." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Food Science and Technology.

Bernadine H. Meyer, Major Professor

We have read this thesis and recommend its acceptance:

Jane R. Savage, Ada Marie Campbell

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

February 28, 1974

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Vice Chancellor
Graduate Studies and Research

TENSILE PROPERTIES OF BEEF SEMITENDINOSUS MUSCLE AS AFFECTED BY HEATING RATE AND END POINT TEMPERATURE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee

Carolyn Lucille Barker

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ABSTRACT

Tenderness of meat is one of its most important attributes of quality. The purpose of this study was to study the effect of heating rate (comparable to oven roasting at 93° and 149°C) and end point temperature (50°, 60° and 70°C) on tensile properties of muscle fibers and connective tissue of beef semitendinosus muscle. Cores of meat were heated in tubes in a water bath "programmed" to produce the desired rate of heating. Samples were evaluated by Warner-Bratzler shears and by Instron measurements of breaking strength and work of rupture. Tensile measurements with fibers parallel to the stress were interpreted as reflecting the heat effects on the muscle fibers, whereas measurements with fibers perpendicular to the stress were considered representative of the heat effects on the connective tissue.

Slow rate of heating resulted in lower ($P<0.01$) shear values than heating at the fast rate. Shear values decreased significantly ($P<0.01$) between 50° and 60°C and reached a minimum at 67°C. Although shears were lower at 70° than 60°C the decrease was not significant. Muscle fibers (fibers oriented parallel) were more resistant ($P<0.001$) to shearing than the connective tissue (fibers oriented perpendicularly).

Breaking strength and work of rupture were not significantly affected by rate of heating. A significant interaction ($P<0.001$) between end point temperature and fiber direction was illustrated by polynomial curves. Fibers oriented parallel to the stress decreased significantly ($P<0.01$) in breaking strength and work of rupture from 50° to 60°C and

from 60° to $70^{\circ}C$. Minimum breaking strength and work of rupture were obtained at $67^{\circ}C$; thereafter as internal temperature increased breaking strength and work of rupture started to increase. A nonsignificant decrease in breaking strength and work of rupture occurred with increasing internal temperature when fibers were oriented perpendicularly to the stress. Major changes in tensile strength occurred in the muscle fibers rather than in the connective tissue.

Instron measurements in this study give no explanation for the reported increase in tenderness of meat heated at slow rates. Further work might be directed toward studying the changes in the muscle fibers which resulted in the decreased tensile strength that occurred during the early stages of heating.

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CHAPTER I

INTRODUCTION

Factors affecting tenderness of meat have been investigated in numerous studies. Connective tissue and muscle fibers, the two structural components of meat, are recognized as the constituents which play major roles in tenderness. The effect of heating on these two structural elements and consequently on the tenderness of meat is very complex. Although the effect of heating on the changes in tenderness of meat has been studied extensively, many questions remain unanswered. Draudt (1972) and Paul (1963) have theorized that heat related changes in collagenous connective tissue have a tenderizing effect while hardening of the myofibrillar proteins has a toughening effect. It is generally accepted that heat of cooking does not alter the tenderness of elastic connective tissue.

In several investigations it was shown that slow heating rates in the range of 66° to 121°C oven temperature produced more tender beef roasts as measured by sensory panel and by Warner-Bratzler shears than faster rates of heating in the range of 149-163°C oven temperatures (Cover, 1943; Bramblett et al., 1959; Bramblett and Vail, 1964; Bayne et al., 1969). Reasons for the improved tenderness with the slow heating rates have not been elucidated. Most of these investigators theorized that the slower rate of heat penetration at the lower oven temperature was conducive to collagen solubilization. Pursuing this theory Bayne et al. (1971) measured changes in the alkali insoluble collagen of beef top rounds roasted at 93° and 149°C. However, they found no difference in the decrease in collagen with the two heating rates although the slowly cooked roasts were significantly more tender.

In the majority of the studies of meat tenderness shearing devices which cut across the muscle fibers and surrounding connective tissue have been used to assess tenderness objectively. In recent years Stanley et al. (1971, 1972) and Bouton and Harris (1972a,b) have used the Instron Universal Testing Machine to investigate tensile properties of meat. Bouton and Harris have considered that the breaking strength of meat with fibers oriented parallel to the stress can be used as a measure of the muscle fiber component of tenderness, while the connective tissue component can be studied by breaking samples with the fibers oriented perpendicularly to the stress.

The purpose of the present investigation was to study the effect of two heating rates and three end point temperatures on the tenderness of muscle fibers and connective tissue of beef using the technique of Bouton and Harris (1972a,b) with the Instron. For this purpose beef semitendinosus muscle was used as the test product. Cores 2.5 cm in diameter x 6.25 cm long were removed from each muscle with muscle fibers running parallel to the length of the core in half the samples and perpendicular in the other half. The cores were heated in glass tubes in a water bath at rates comparable to oven roasting 2-kg top rounds of beef in a 93°C to 149°C oven to end points of 50, 60 and 70°C. After heating the cores were evaluated by the Warner-Bratzler Shear and the Instron Universal Testing Machine. Shear values were obtained by shearing once at each end of each core. The remaining core then was sliced and cut into strips to break on the Instron. Breaking strength and work of rupture were the measures used to evaluate the Instron data.

CHAPTER II

REVIEW OF LITERATURE

I. THE EFFECT OF HEATING RATE ON THE TENDERNESS OF BEEF

Tenderness is the most important attribute of meat quality to the consumer (Bailey, 1972). The effect of heat on the tenderness of meat therefore has been the subject of many investigations. In several studies roasting of beef at very low oven temperatures (66-121°C) for long periods of time has been shown to produce more tender meat than higher temperature (149-163°C), shorter time methods of oven roasting.

In a 1943 study by Cover paired cuts of beef were roasted at 80° and 125°C. A tender product was always produced when the rate of heat penetration was slow enough to require 30 hours or more to lose the pink color. With less time the roasts were not always tender.

Bramblett et al. (1959) found that U. S. Standard grade beef round roasts cooked at 63°C for 30 hours were more tender than pair mates heated in a 68°C oven for 18 hours. The longer the roasts were maintained at an internal temperature in the range of 57° to 60°C the lower were the shear values and therefore the more tender was the meat.

In 1964, Bramblett and Vail found that muscles from rounds of U. S. Good grade carcasses heated to an internal temperature of 65° in a 69°C oven were more tender than pair mates heated to 65° in a 93°C oven. The slow rate of heating required two to four times longer than the fast rate to reach the same end point.

The effect of two rates of heating on paired large and small rib and top round roasts was studied by Bayne et al. (1969). Roasts heated at 93°C to an end point of 67°C were more tender as measured by shear values ($P<0.001$) than those heated at 149°C to an end point of 70°C. Sensory panel scores confirmed that the slower rate of heating produced more tender meat.

Laakkonen et al. (1970) found an increase in the tenderness of bovine muscles with low-temperature, long-time heating. A water bath was used to heat slices of semitendinosus, longissimus dorsi and rectus femoris muscles in plastic pouches for a total cooking time of 10 hours. The temperature of the water bath was increased at a rate of 0.1°C per minute to 60°C and held constant for the remainder of the heating period. The greatest increase in tenderness occurred between the fourth and sixth hours of heating. During that period of time temperature increased from 50° to 60°C in the meat.

Machlik and Draudt (1963) studied the effect of various time-temperature treatments on the shear values of beef semitendinosus muscles. Small cores of meat were heated in tubes in a water bath for varying lengths of time at temperatures ranging from 50° to 90°C. A decrease in shear values in the 55-56°C range was attributed to collagen shrinkage. Shear values increased with heating at 66-80°C and decreased again in the 80-90°C range. Time required for the collagen shrinkage reaction varied with temperature at which this meat was heated.

Draudt (1972) theorized that heat related changes in connective tissue have a tenderizing effect while hardening of the myofibrillar proteins has a toughening effect. He proposed that changes in shear values at various temperatureswere attributed to the following factors:

40°C The mechanical properties of meat have not been significantly affected by heat, therefore, shears at this point are indicative of initial tenderness.

50°C Denaturation of most of the contractile proteins has occurred. Collagen shrinkage or solubilization and hardening of the myofibrillar proteins have not yet occurred. Shears are therefore, at a maximum point prior to collagen shrinkage.

60°C Reflects the effect of the collagen shrinkage reaction without any appreciable myofibrillar hardening.

74°C The magnitude of hardening and very limited collagen solubilization can be seen.

94°C Reflects solubilization of collagen.

II. USE OF INSTRON TO MEASURE TENDERNESS OF MEAT

Methods of measuring meat texture (specifically tenderness) are described by Szczesniak and Torgeson (1965). Although they point out that the Warner-Bratzler Shear is one of the most popular instruments for objective measurement of meat tenderness, newer instruments are now being used. In recent studies the Instron Universal Testing Machine has been used to measure compression and tensile properties of food materials (Bourne et al., 1966). A strip-chart recorder that is an integral part of the machine draws a force-distance curve for every test. The working parts of most texture-measuring devices used in the food industry can be used to obtain maximum force, slope, compression, area, work, plateau height, relaxation, and recovery. These parameters can be applied to different food products.

Pool (1967) used the Instron to measure the cohesive force holding the fibers and fiber bundles of poultry meat together, i.e., the connective tissue tenacity (CTT). Uniform cylinders of cooked muscle with the fibers parallel to the plane ends of the cylinder were cut out of chicken Pectoralis major muscles. Prior to obtaining the cylinders the muscles were cooked in boiling water to 85°C in the center of each muscle. The ends of each cylinder were attached to metal plates by a special adhesive that forms strong bonds with moist tissue. Force and work required to tear the meat sample apart were recorded. Work (integral of force over time and termed CTT in this study) rather than maximum force was found to be the most meaningful and reproducible value in relation to cohesiveness. Connective tissue tenacity was directly correlated with alkali insoluble hydroxyproline ($r=0.91$, $P<0.001$) and inversely related to cooking time.

Stanley et al. (1971) used the Instron to measure the work of rupture, breaking strength, break elongation, elasticity and stress relaxation of uncooked rabbit and beef muscle. The samples of meat were cut to 5.0 cm in length and about 0.2-0.5 cm^2 cross-sectional area. The experiments were conducted in a conditioned room at 70°F. The samples were kept in an ice bath prior to use. The tensile properties as evaluated by Stanley et al. were:

> Breaking strength or breaking load in lb force/g sample; break elongation or strain required to rupture the sample as a percentage of the original 3.5 cm sample between the jaws; specific work

> of rupture or the area under the stress-strain curve in inch-lb/g sample. Time effects measured included elasticity which was taken as the area under the stress-strain curve following 1 min of cycling to 115% elongation as a percentage of the initial area, and relaxation expressed as the amount of stress loss in 1 min at 115% elongation as a percentage of the original stress.

These methods were used to measure variation in muscle type, aging and post-mortem treatments. Breaking strength was the best predictor of tenderness as measured by a sensory panel.

In a later (1972) study by Stanley et al., the Instron was used on raw porcine psoas muscle to measure: Breaking strength (g required to break the sample/g sample); break elongation (percent elongation at the break); stress relaxation (percent stress lost from a sample held for 1 min at 14% extension from 3.5 cm up to 4.0 cm); and elasticity (percent reduction in work required to extend the sample 14% after 1 min of cycling). Samples were prepared by dissecting bundles of muscle fibers free of any visible fat or connective tissue and cutting strips parallel to the fibers. The sample strips were clamped to the load cell and cross-head with type 2A fiber clamps. Sample dimensions were: total length, 5.0 cm; length available for stretching after clamping, 3.5 cm; and cross-sectional area, approximately 10 mm^2. All samples were weighed on an analytical balance prior to testing. Instrument parameters were: crosshead speed, 30 cm min^{-1}; chart speed, 30 cm min^{-1}; and full scale deflection, 100 g. They found that breaking strengths of the small longitudinal strips of tissue were the best objective predictors of sensory tenderness.

Bouton and Harris (1972a) used the Instron to measure compression (chewiness) and adhesion of beef cooked at different temperatures for various times. Samples of approximately equal weight were placed in polyethylene bags which were tightened around the samples and held by metal clips. Samples were completely immmersed, for selected times, in water baths at the desired cooking temperature (± 0.5°C). Samples weighing 150-200 g were required for all the mechanical measurements. Instron "adhesion" was measured as the force and work required to pull apart 1 cm^2 (1.5 x 0.67 cm) samples whose fibers were oriented perpendicularly to the direction of strain. Adhesion values decreased more rapidly than compression measurements when the meat was cooked to 90°C. Compression was measured on the Instron by driving vertically a 0.63 cm diameter flat-ended plunger 80% of the way through a 1.30 ± 0.01 cm thick sample of the cooked meat. The meat samples were cut and presented so that the fibers were perpendicular to the direction of plunger penetration. The authors concluded that compression measurements depend on fiber strength, as well as on adhesion between the fibers.

Bouton and Harris (1972b) also used the Instron to study the effects of aging on bovine and ovine muscles. Adhesion and "fiber tensile strength" were the parameters measured. The tensile measurements with the fibers oriented perpendicularly to the stress (adhesion) were considered to be a measure of the strength of the connective tissue holding the fibers together. Tensile measurements on the samples with the fibers parallel to the applied strain were taken primarily as a measure of "fiber tensile strength" although there was some contribution from connective tissue. Samples shaped into blocks measuring approximately 12 x 6 x 4 cm and weighing 180-200 g were cooked for

1½ hour at 60° and $90^{\circ}C$ in a water bath in the first aging experiment, and at 60° and $80^{\circ}C$ for the second experiment. Double bladed scapels were used to cut rectangular sectioned samples of 1 sq cm (1.5 x 0.67 cm) with the meat fibers lying parallel or perpendicular to the face of greatest area. To avoid breakage in the pneumatically operated Instron "jaws," the effective cross-sectional area of the samples was reduced from 1.0 to 0.44 cm^2 by preparing them in the dumb-bell shapes conventionally used for tensile testing. Fiber tensile strength was significantly higher in beef muscle cooked at 80° than at $60^{\circ}C$.

CHAPTER III

PROCEDURE

I. SOURCE OF MEAT

Seven USDA Choice semitendinosus muscles were procured from East Tennessee Packing Company in Knoxville, Tennessee and placed in freezer storage prior to use in the study.

II. PREPARATION OF SAMPLES FOR HEATING

Each frozen muscle was cut into four 6.25 cm long sections across the fibers. Fat surrounding the muscle and epimysial connective tissue were removed. While still slightly frozen, six cores, 2.5 cm. in diameter x 6.25 cm long, were removed parallel to the muscle fibers and six cores were also removed perpendicular to the muscle fibers. The parallel and perpendicular cores were assigned randomly to end point temperature-heating rate treatments. Four cores, two parallel and two perpendicular, were taken for holding thermocouples to monitor the temperature rise in the test cores.

III. HEATING

Each core of meat was placed in a PYREX centrifuge tube, 2.5 cm in diameter (50 ml), and then placed in a shaker water bath containing cold water (2-3°C). Two small marbles were placed in the bottom of each tube before inserting the cores to hold the cores up out of the drip. The temperature of the water bath was increased gradually so that the temperature rise in the center of the cores of meat would reproduce that of a 2-kg top round roast cooked in a 93°C oven for approximately 9½ hours, or in a 149°C oven for approximately 2½ hours. These treatments were designated as slow and fast heating rates, respectively. One tube containing a parallel core and one tube containing a perpendicular core were removed at end points of 50°, 60°, and 70°C for each heating rate. After heating, the tubes were cooled in an ice bath for 15 minutes. When cool the cores were placed on watch glasses, covered with plastic wrap, and stored in the refrigerator overnight prior to shearing.

IV. SHEARS

The Warner-Bratzler Shear Apparatus was used to obtain two shear values, one at each end of each core leaving the center intact for preparation of strips for tensile testing. The cores then were wrapped individually in plastic wrap and freezer paper and placed in the freezer until they were ready to slice for tensile testing.

V. PREPARATION OF SAMPLES FOR TENSILE TESTING

Each frozen core was sliced longitudinally into 2 mm thick slices with a hand-operated meat slicer. Each slice was cut into 5 mm wide strips using a double bladed scalpel made by soldering two scalpels together. All strips were cut to 4 cm in length. The cross section of each strip was 10 mm^2. The bundles of strips were wrapped in plastic wrap according to heat treatments and held in the refrigerator until tested on the Instron. The weight of each strip was recorded; then the strips were tightened in the grips of the Instron. The rationale for the breaking strength procedure on the Instron was derived from Bouton and Harris (1972b):

> The tensile measurements on the samples, which were held with the fibers oriented perpendicular to the strain, were considered to be a measure of the strength of the connective tissue holding the fibers together. These measurements are referred to as adhesion measurements.* Tensile measurements on the samples with the fibers parallel to the applied strain were taken primarily as a measure of "fiber tensile strength"* although there was some contribution from connective tissue.

VI. INSTRON MEASUREMENTS

The maximum force required to break each strip was recorded by the Instron as a force-distance curve. A 5,000 g cell was used and the Instron was operated so that full deflection was equal to 500 g. Crosshead speed was 50mm/min and chart speed was 100mm/min. The length of the strip available for breaking after clamping into the grips was 2.5 cm. Breaking strength (Stanley et al., 1972) was the grams of force required to break the strip per g of dry weight. The following formula was used:

$$\text{Breaking Strength (g force/g dry wt of strip)} = \frac{\text{Maximum force to break (g)}}{\text{wt of strip (g)} \times \text{\% dry wt}/100}$$

The data were calculated on five or six satisfactorily broken strips from each heat treatment for each of the seven test muscles, for both

*The terms "adhesion" and "fiber tensile strength" as used by Bouton and Harris refer to characteristics of the muscle tissue with the above fiber orientations.

parallel and perpendicularly strained fibers. A break was considered satisfactory when the strip was not cut by the grips holding the strip. Work of rupture (maximum force x distance) was calculated. The following formula was used to calculate work of rupture:

$$\text{Work of Rupture (g-cm/g dry wt of strip)} = \frac{\text{Maximum force to break (g)} \times \text{Distance (cm)}}{\text{wt of strip (g)} \times \text{\% dry wt}/100}$$

VII. MOISTURE

Approximately 5 g samples of minced meat from each heat treatment were placed in pre-weighed aluminum dishes. The samples were dried in a vacuum oven overnight at 60°C until they reached a constant weight. The percentage of dry matter for each sample was calculated. The moisture content of the strips was expected to vary with end point temperature, therefore all Instron measurements were calculated on a dry-weight basis (Table 8, Appendix).

VIII. STATISTICAL ANALYSIS

The experiment was planned as a randomized complete block which consisted of seven blocks or replications. Each muscle constituted one block. Analysis of variance and orthogonal comparisons were used to study the functional relationship between heating rate and end point temperature for shear values, breaking strength and work of rupture. When significance was found the Student-Newman-Keuls Test (Sokal and Rohlf, 1969) was applied. Correlation coefficients for Warner-Bratzler shear values versus Instron measurements were calculated.

CHAPTER IV

RESULTS AND DISCUSSION

I. HEATING RATE DATA

Mean time-temperature curves for heating beef semitendinosus cores at the two rates are illustrated in Figure 1. Mean time to reach 70°C for the slow method was 563 minutes, approximately 3.5 times the 162 minutes required to reach an internal temperature of 70°C with the fast rate of heating. Mean times to reach each of the end points in both parallel and perpendicular cores are presented in Table 1. Less time was required to heat both the parallel and perpendicular cores to each end point at the fast rate of heating. Time to reach each end point was essentially the same for parallel and perpendicular cores.

II. SHEAR VALUES

Shear values of the cores for the seven replications of each treatment are shown in Table 2. In Table 3 are shown the results of the analysis of variance of these shear values.

Shear values differed with respect to rate of heating. Cores heated at the slow rate were more tender than those heated at the fast rate ($P<0.01$). Mean shear values for the two rates were 8.8 kg and 10.2 kg for slow and fast heating respectively. Earlier studies (Bramblett et al., 1959, Bramblett and Vail, 1964 and Bayne et al., 1969) indicated that slow heating of beef roasts produced more tender meat

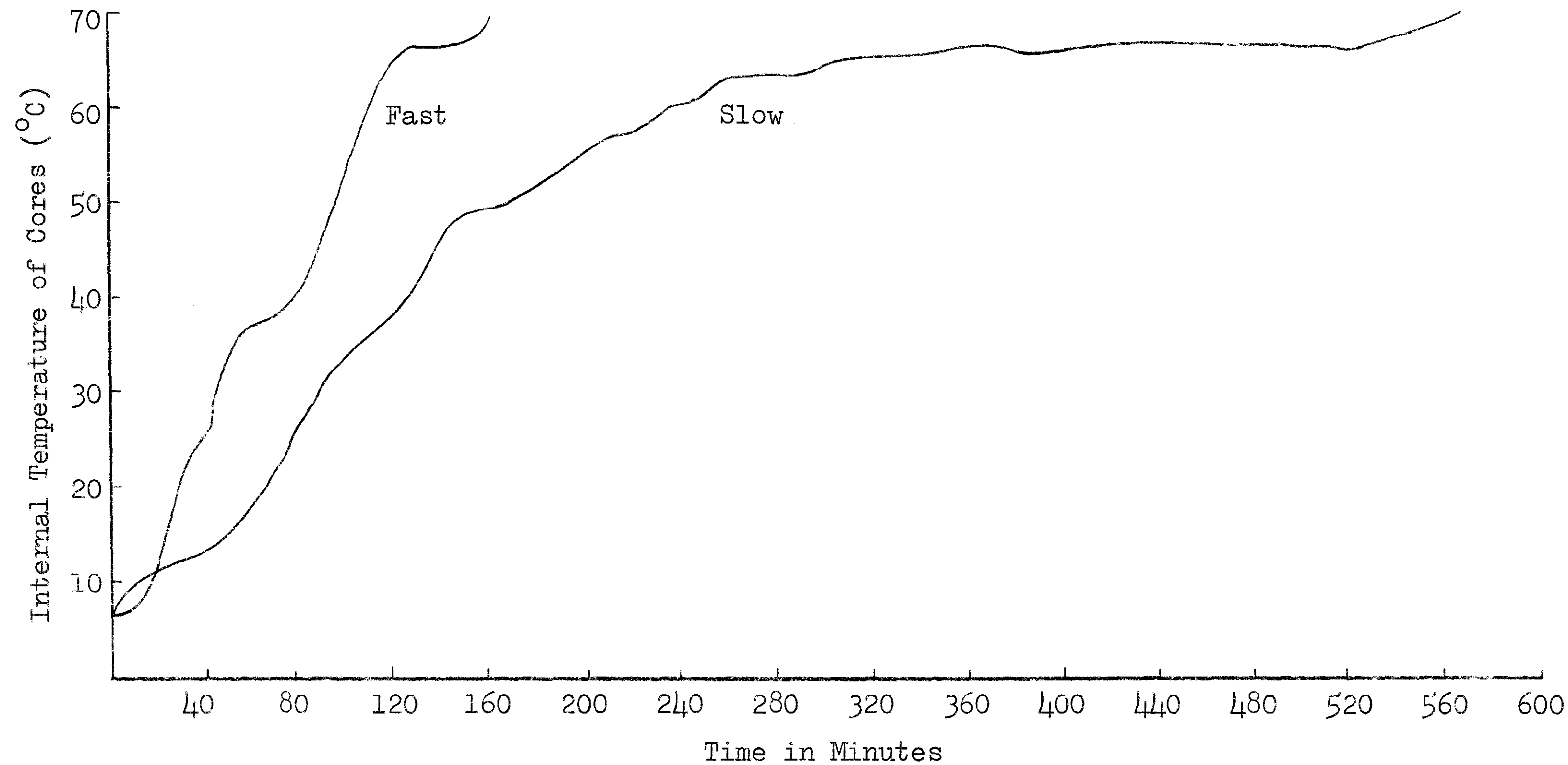

Figure 1. Mean time-temperature curves for heating beef semitendinosus cores at two rates.

TABLE 1. Mean Time Required to Heat Parallel and Perpendicular Beef Semitendinosus Cores at Two Rates to Three End Points

	Minutes[a]					
	Slow Heating			Fast Heating		
	50°C	60°C	70°C	50°C	60°C	70°C
Parallel Cores						
Mean	166.3	237.3	562.1	94.1	109.0	161.7
± Standard Error	3.2	3.0	6.1	1.1	1.3	2.5
Perpendicular Cores						
Mean	164.4	236.7	563.3	94.4	109.4	162.6
± Standard Error	4.1	3.4	6.3	1.5	1.6	3.7

[a]Mean of seven replications.

TABLE 2. Shear Values of Beef Semitendinosus Cores Heated at Two Rates to Three End Points

Muscle Number	Shear Values[a] (kg)											
	Parallel						Perpendicular					
	Slow			Fast			Slow			Fast		
	50°C	60°C	70°C	50°C	60°C	70°C	50°C	60°C	70°C	50°C	60°C	70°C
VI	14.0	6.2	5.4	22.8	8.5	7.8	16.3	5.6	4.9	15.7	5.5	8.8
VII	18.0	8.3	5.9	20.2	7.7	7.1	18.5	5.6	3.8	18.8	6.0	4.8
III	13.9	7.5	4.8	15.6	5.2	6.0	14.4	4.7	4.4	10.3	4.5	5.1
V	17.4	9.4	6.0	13.5	12.8	9.3	12.3	4.7	4.2	18.8	8.0	7.3
I	17.9	7.0	5.8	17.7	9.3	7.6	16.4	5.2	3.3	12.7	6.0	7.0
IV	16.0	7.4	6.2	15.1	6.9	7.5	10.0	4.4	3.9	15.7	4.7	4.7
II	17.6	8.2	6.8	14.3	10.3	9.4	5.6	6.1	3.9	16.6	6.7	8.3
Mean	16.4	7.7	5.8	17.0	8.7	7.8	13.4	5.2	4.0	15.5	5.9	6.6
± Standard Error	0.7	0.4	0.2	1.3	0.9	0.4	1.7	0.2	0.2	1.2	0.4	0.6

[a]Means of two shears.

TABLE 3. Analysis of Variance of Shear Values, Breaking Strength and Work of Rupture

Source	Degrees of Freedom	Mean Squares: Shear Values	Mean Squares: Breaking Strength	Mean Squares: Work of Rupture
Rate	1	46.8**	302.5	109,433.5
End Point	2	778.0***	194,483.5***	8,409,178.6***
Linear	1	1,264.5***	331,993.2***	15,050,292.5***
Quadratic	1	291.5***	56,973.8**	1,768,064.8**
Fiber Direction	1	96.6***	1,649,425.4***	24,451,542.7***
Rate x End Point	2	3.4	10,713.0	133,054.8
Fiber Direction x End Point	2	2.4	136,564.8***	4,859,403.1***
Fiber Direction x Rate	1	2.0	69.1	57,112.1
Rate x Fiber Direction x End Point	2	1.4	3,729.8	72,071.2
Animal	6	9.9	9,281.5	502,013.1*
Residual[a]	66	4.4	7,044.5	174,068.9

[a]Error term.

*P<0.05; **P<0.01; ***P<0.001.

than rapid heating. Bayne et al. (1969) reported that roasts heated to 67° in a 93°C oven had lower shear values ($P < 0.001$) than those heated to 70° in a 149°C oven.

There was a highly significant differences ($P < 0.01$) in shear values with respect to the orientation of the muscle fibers. Mean shear value for the parallel cores was 10.8 kg and for the perpendicular cores 8.4. This could be interpreted as indicating the muscle fibers are inherently more resistant to shearing than the surrounding connective tissue.

Mean shear values of cores heated to three end point temperatures (T) without respect to heating rate are presented in Table 4. Shear values differed significantly ($P < 0.001$) with respect to end point temperature (Table 3). Shear values decreased ($P < 0.01$) with heating from 50° to 60°C (Student-Newman-Keuls Test, Table 4). Although shear values were lower at 70°C than at 60°C, the decrease was not significant. The polynomial curve shown in Figure 2 is a representation of shear values as a function of end point. The curve was plotted from the following equation:

$$\text{Shear} = 177.6 - 5.2T + 0.04T^2$$

Minimum shear values were obtained at about 67°C. Shears began to increase slightly from 67 to 70°C.

III. TENSILE PROPERTIES

In making the measurements on the Instron, data obtained when fibers were oriented parallel to the stress were interpreted as reflecting the heat effects on the muscle fibers. Measurements made with fibers

TABLE 4. Mean Values for Shear Force, Breaking Strength and Work of Rupture of Beef Semitendinosus Cores Heated to Three End Points

End Point	Shear Force (kg)[a]	Breaking Strength (g)[a]	Work of Rupture (g-cm)[a]
50	$15.6^{b} \pm 0.2$	$330.2^{b} \pm 9.2$	$1475.6^{b} \pm 45.5$
60	$6.9^{c} \pm 0.2$	$198.0^{c} \pm 9.2$	$649.6^{c} \pm 45.5$
70	$6.1^{c} \pm 0.2$	$176.2^{c} \pm 9.2$	$438.8^{c} \pm 45.5$

[a]Mean of seven replications.

[b,c]Means in the same column with like superscripts do not differ ($P<0.01$).

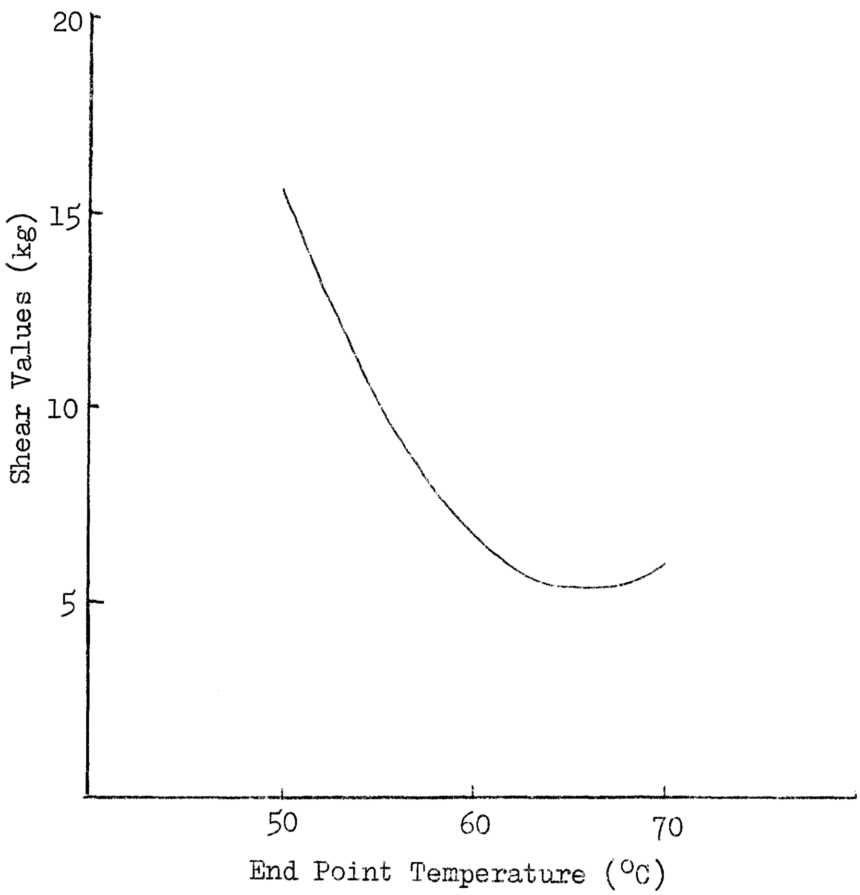

Figure 2. Shear values as a function of end point temperature.

oriented perpendicularly were considered representative of the heat effect on connective tissue.

Breaking Strength

Average values for breaking strength of the strips of semitendinosus muscle for the seven replications of each treatment are presented in Table 5. Results of the analysis of variance are shown in Table 3, p. 19. There was no significant difference in breaking strength with respect to rate of heating. Mean breaking strength values were 236.7 g and 232.9 g for slow and fast heating rates respectively.

Perpendicular cores had lower breaking strength than the parallel cores. Mean breaking strength for the parallel cores was 374.9 g, whereas for the perpendicular cores the mean breaking strength was 94.7 g. ($P < 0.001$, Table 3, p. 19). This indicates that the muscle fibers were more resistant to breaking than the connective tissue.

Mean breaking strength of cores heated to three end point temperatures (T) without respect to heating rates or fiber orientation are presented in Table 4, p. 21. Breaking strength decreased ($P < 0.001$) as end point increased (Table 3, p. 19). Results of the Student-Newman-Keuls Test (Table 4, p. 21) show that a significant decrease in breaking strength occurred between 50° and 60°C. A small further decrease from 60°C to 70°C was not significant.

Polynomial curves presented in Figure 3 show the relationship of end point temperature and fiber direction to breaking strength. Data for parallel and perpendicular observations were analyzed separately

TABLE 5. Breaking Strength of Beef Semitendinosus Cores Heated at Two Rates to Three End Points

Muscle Number	Breaking Strength[a] (g)											
	Parallel						Perpendicular					
	Slow			Fast			Slow			Fast		
	50°C	60°C	70°C	50°C	60°C	70°C	50°C	60°C	70°C	50°C	60°C	70°C
VI	885.2	341.6	213.5	582.3	316.8	302.8	80.6	103.6	104.4	93.2	71.9	182.9
VII	622.2	317.1	261.3	666.8	411.1	350.4	85.3	108.6	96.6	59.8	121.0	80.2
III	357.4	324.7	213.9	394.1	162.0	222.7	152.6	227.6	64.5	88.6	55.4	39.6
V	511.3	301.2	226.6	531.2	389.1	234.5	144.2	50.9	77.1	158.4	90.3	81.3
I	769.3	158.3	360.3	451.8	353.5	238.8	88.1	45.5	37.8	90.2	90.3	139.2
IV	334.8	470.3	184.5	439.1	360.7	394.8	160.3	77.3	65.8	118.6	93.4	60.4
II	625.3	191.2	262.3	533.8	199.0	279.5	114.7	63.4	60.2	106.7	47.6	98.5
Mean	586.5	300.6	246.0	514.2	313.2	289.1	118.0	96.7	72.3	102.2	81.4	97.4
± Standard Error	76.7	38.9	21.7	35.4	36.2	24.5	13.0	23.7	8.6	11.6	9.5	18.5

[a]Means of six breaks on Instron.

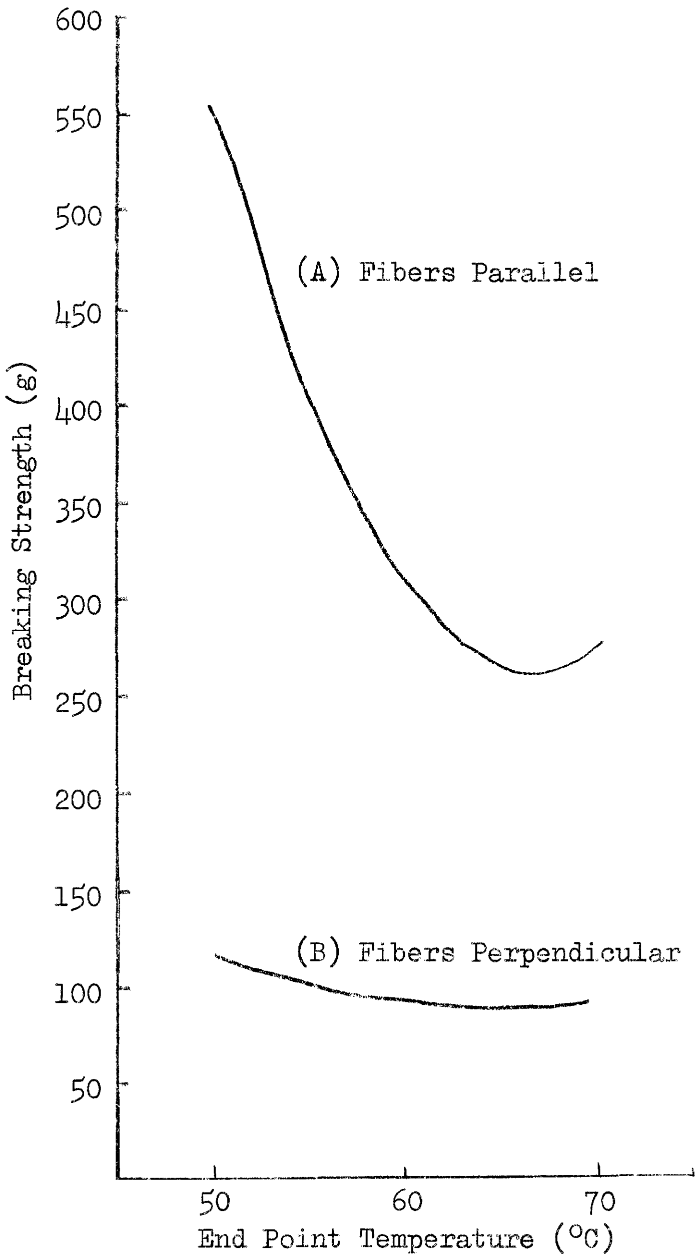

Figure 3. Breaking strength parallel (A) and perpendicular (B) as a function of end point temperature.

because of the significant ($P<0.001$) interaction between end point and fiber direction. Orthogonal comparisons (Table 6) for the curve with fibers oriented parallel to the stress show a significant decrease in breaking strength from 50° to 60°C and from 60° to 70°C. Minimum breaking strength was obtained at about 67°C (Curve A, Figure 3) and increased slightly by 70°C. Orthogonal comparisons for Curve B (fibers oriented perpendicularly) show a nonsignificant decrease in breaking strength as internal temperature increases. These data indicate that most of the change in tensile strength occurred in the muscle fibers rather than in the connective tissue as internal temperature increased from 50° to 70°C.

The functional relationship between breaking strength and end point temperature was depicted by the following polynomial equations:

$$\text{Breaking Strength Parallel} = 4{,}829.3 - 136.6T + 1.0T^2$$

$$\text{Breaking Strength Perpendicular} = 468.3 - 11.4T + 0.08T^2$$

Work of Rupture

In Table 7 are shown the average values for work of rupture for seven replications. Work of rupture was calculated by multiplying the maximum force to break the fiber by the distance to break on the breaking strength curve. Results of the analysis of variance are presented in Table 3, p. 19. As with breaking strength, rate of heating did not significantly affect work of rupture values. Mean work of rupture values were 818 and 891 g-cm for slow and fast heating rates respectively.

TABLE 6. Orthogonal Comparisons of Mean Breaking Strength and Work of Rupture of Parallel and Perpendicular Cores Heated to Three End Points

	Breaking Strength (g)			Work of Rupture (g-cm)		
	50°C	60°C	70°C	50°C	60°C	70°C
Parallel Cores	550.4[a]	306.9[b]	267.6[c]	2,489.1[a]	1,023.1[b]	670.2[c]
± Standard Error	41.8	25.6	16.8	248.5	111.1	69.2
Perpendicular Cores	110.1[a]	89.1[a]	84.9[a]	462.1[a]	275.8[a]	207.4[a]
± Standard Error	8.6	12.4	10.4	31.4	44.0	31.8

[a,b,c]Means for breaking strength or for work of rupture with like superscripts in the same row do not differ ($P < 0.01$).

TABLE 7. Work of Rupture of Beef Semitendinosus Cores Heated at Two Rates to Three End Points

Muscle Number	Work of Rupture (g-cm)[a]											
	Parallel						Perpendicular					
	Slow			Fast			Slow			Fast		
	50°C	60°C	70°C	50°C	60°C	70°C	50°C	60°C	70°C	50°C	60°C	70°C
VI	4827	1039	472	3023	1277	836	329	410	280	426	215	491
VII	3085	1216	538	3850	1460	1231	456	391	293	335	489	259
III	1633	838	344	2022	390	672	544	651	115	497	153	70
V	2132	1143	434	2393	1577	916	577	146	149	702	179	233
I	2498	456	658	1798	993	515	361	178	156	516	288	331
IV	1488	1560	334	1789	1325	893	502	253	120	553	352	134
II	2125	526	624	2183	523	916	408	150	136	264	106	236
Mean	2541	968	486	2437	1078	854	454	297	164	470	254	250
± Standard Error	431	148	48	285	175	84	35	76	34	55	50	51

[a]Means of six breaks on Instron.

Work of rupture values (Table 3, p. 19) for perpendicular cores were lower ($P < 0.001$) than the values for the parallel cores. Mean work of rupture values were 1394 g-cm for the parallel cores and 315 g-cm for the perpendicular cores. This indicates that the muscle fibers required more work to break than the connective tissue.

Curves from the Instron show a difference in tensile properties between parallel and perpendicularly stressed fibers. Curves for muscle fibers generally were high, i.e. showed high maximum forces, and were narrow-based, i.e. showed relatively short time for breakage; curves for perpendicularly stressed fibers showed low maximum forces and relatively long time for breakage. High maximum force for the parallel curves indicates that the muscle fibers were more resistant to breaking than the connective tissue. Curves for the perpendicular fibers with a long time to break show the elasticity of adhering connective tissue.

Mean values for work of rupture of cores heated to three end point temperatures (T) without respect to heating rate are shown in Table 4, p. 21. As end point temperature increased work of rupture values decreased ($P < 0.001$, Table 3, p. 19). There was a significant decrease in work of rupture values between 50° to $60^{\circ}C$ (Student-Newman-Keuls Test, Table 4, p. 21). As with breaking strength, heating from 60° to $70^{\circ}C$ further decreased work of rupture, but not significantly.

Polynomial curves (Figure 4) show work of rupture as a function of end point temperature and fiber orientation. A significant interaction ($P < 0.001$) between end point and fiber orientation is shown by the two curves. These curves are similar to the breaking strength

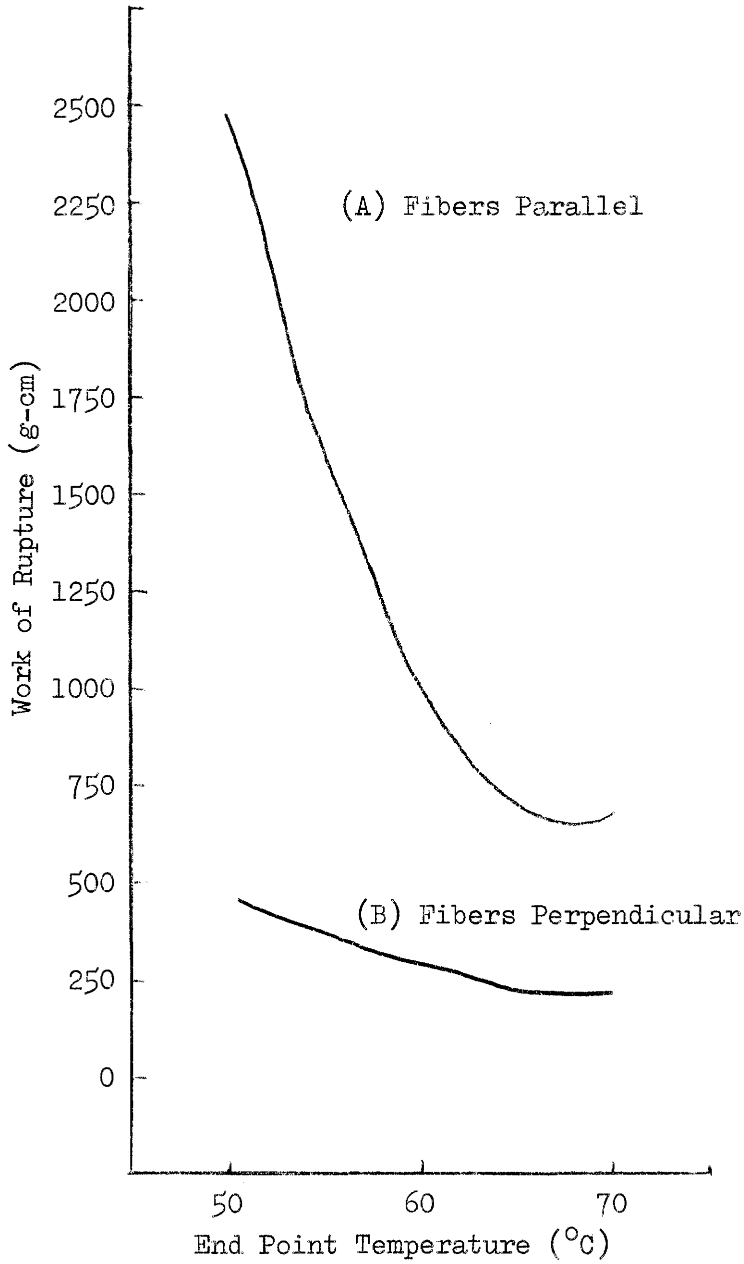

Figure 4. Work of rupture parallel (A) and perpendicular (B) as a function of end point temperature.

curves (Figure 3, p. 25), again indicating the muscle fibers required more work to rupture than the connective tissue. The following polynomial equations illustrate the functional relationship between work of rupture and end point temperature:

$$\text{Work of Rupture Parallel} = 26{,}514.5 - 758.8T + 5.6T^2$$

$$\text{Work of Rupture Perpendicular} = 3{,}164.3 - 83.6T + 0.6T^2$$

According to the analysis of variance in Table 3, page 19, there was a significant difference ($P<0.05$) among animals for work of rupture. However, the range test (Student-Newman-Keuls Test) did not detect the difference. If the purpose of this study had focused on investigating the difference in animals, more than one sample would have been evaluated for each treatment and better control of source of meat would have been desired.

The correlation coefficient between shear values and breaking strength was significant ($P<0.01$) for the parallel observations ($r=0.56$). However, the correlation coefficient for the perpendicular values ($r=0.26$) was not significant. There was significant correlation ($P<0.01$) between work of rupture and shear values for both parallel ($r=0.75$) and perpendicular ($r=0.80$) observations.

IV. DISCUSSION

Since the Instron Universal Testing Machine had been acquired recently by the Food Science and Food Systems Administration Department, this study was carried out on an exploratory level. Review of the literature shows only a few studies involving the use of the Instron to measure tensile properties of meat. However, due to the versatility of the Instron, it is becoming more popular as an instrument to measure parameters of food objectively.

The present investigation has focused on the separate heat effects on muscle fibers and on the connective tissue when meat was heated at slow and fast rates. Earlier workers (Bramblett et al., 1959, Bramblett and Vail, 1964 and Bayne et al., 1969) have reported an improvement in tenderness with slow heating rates. It has been speculated that this improvement in tenderness resulted from softening of the connective tissue. Results of the present study raise some questions about the validity of this speculation.

To the extent that the measurements truly represented changes in the muscle fibers and connective tissue, the effect of heating on muscle fibers indicated a significant decrease in fiber tensile strength during heating from 50^{o}-$67^{o}C$ with minimum shear, breaking strength and work of rupture values at about $67^{o}C$. These data show that during the early stages of heating meat up to about medium doneness major softening occurs in the muscle fibers. This was accompanied by a much less softening of the connective tissue. Above $68^{o}C$ there was a tendency for shear values, breaking strength and work of rupture of muscle fibers to increase as illustrated by the polynomial curves. This observation tends to confirm the theory of Draudt (1972) that hardening of muscle fibers occurs at $70^{o}C$ and above. Bouton and Harris (1972b) found that fiber tensile strength was significantly higher in beef muscle cooked at 80° than at $60^{\circ}C$.

Tensile measurements on the muscle fibers perpendicular to the stress were considered to reflect the effect of the heat treatment on the connective tissue. To the extent that this was a valid assumption polynomial curves show only a gradual nonsignificant decrease in shear, breaking strength and work of rupture values as internal temperature of the muscle tissue increased to $70^{\circ}C$.

While shear values in this and other studies indicated that slow rates of heating produced more tender meat, Instron measurements of tensile properties did not indicate a significant difference in tenderness of meat heated at two rates. Future work might be directed toward exploring changes occurring in muscle fibers which resulted in decreased tensile strength during the early stages of heating.

CHAPTER V

SUMMARY

Changes in tensile properties of muscle fibers and connective tissue as affected by heating at rates comparable to oven roasting 2-kg top rounds at 93° and $149^{\circ}C$ to end point temperatures of 50°, 60° and $70^{\circ}C$ were studied. Cores of beef semitendinosus muscle were heated in tubes in a water bath. Samples from the cores with fibers parallel and perpendicular to the stress were tested on an Instron. Measurements taken on parallel strips were interpreted as reflecting the heat effects on the muscle fibers. Perpendicular measurements were considered representative of the heat effects on the connective tissue. Data were evaluated by Warner-Bratzler shears and Instron measurements of breaking strength and work of rupture.

Shear values were lower ($P<0.01$) at the slow rate of heating than at the fast heating rate. Shear values decreased significantly ($P<0.01$) between 50° and $60^{\circ}C$. Minimum shears were obtained at $67^{\circ}C$. Shear values were lower at 70° than $60^{\circ}C$, but the decrease was not significant. Shears of parallel cores were significantly higher ($P<0.001$) than those of perpendicular cores indicating that the muscle fibers were more resistant to shearing than the connective tissue.

Breaking strength and work of rupture were not significantly affected by rate of heating. Polynomial curves illustrated the difference between measurements of parallel and perpendicularly stressed fibers heated to three end point temperatures. For fibers tested parallel to the stress breaking strength and work of rupture decreased significantly ($P < 0.01$) from 50° to $60^{\circ}C$ and from 60° to $70^{\circ}C$. Minimum breaking strength and work of rupture were obtained at $67^{\circ}C$. As internal temperatures increased a nonsignificant decrease occurred for breaking strength and work of rupture with fibers oriented perpendicularly. These data indicate that heat induced changes in tensile strength occurred in the muscle fibers to a much greater extent than in the connective tissue.

Results of the Instron measurements of this study give no explanation for the reported increase in tenderness of meat heated at slow rates. Investigation of the changes occurring in the muscle fibers might be helpful in explaining the decrease in tensile strength during the early stages of heating.

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APPENDIX

APPENDIX

TABLE 8. Percent Dry Weight of Parallel and Perpendicular Beef Semitendinosus Cores Heated at Two Rates to Three End Points

Muscle Number	Percent Dry Weight											
	Parallel						Perpendicular					
	Slow			Fast			Slow			Fast		
	50°C	60°C	70°C	50°C	60°C	70°C	50°C	60°C	70°C	50°C	60°C	70°C
VI	29.4	33.8	45.5	30.4	34.0	40.9	32.2	36.0	43.3	32.6	33.0	38.9
VII	29.7	34.8	40.1	28.6	31.2	38.5	31.9	33.6	40.4	31.6	33.2	38.8
III	35.6	35.4	39.8	31.4	37.7	42.0	32.2	32.6	42.0	29.6	33.0	38.1
V	34.8	37.8	40.6	31.9	31.5	38.2	31.4	35.5	42.6	32.0	32.9	41.0
I	29.8	31.8	40.2	30.2	33.9	36.0	30.8	34.0	43.3	31.4	32.0	38.0
IV	35.5	33.3	42.2	33.2	32.2	40.8	32.8	36.9	44.3	33.2	33.6	40.6
II	29.7	35.3	41.7	30.1	31.1	36.9	30.1	34.0	41.7	30.0	31.6	38.3
Mean	32.1	34.6	41.4	30.8	33.1	39.0	31.6	34.6	42.5	31.5	32.8	39.1
± Standard Error	1.1	0.7	0.8	0.6	0.9	0.8	0.4	0.6	0.5	0.5	0.3	0.4

VITA

Carolyn Lucille Barker was born in Heber Springs, Arkansas, on October 28, 1949. She attended elementary and high school at Quitman Public Schools where she was graduated in 1968. In September 1968 she entered State College of Arkansas at Conway where she received a Bachelor of Science degree in Home Economics Education in May of 1972.

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